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Ultrasonic wave properties in cortical part of the third metatarsal bone of Thoroughbred

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1. Introduction

If a large animal has a severe bone disease, it cannot support its heavyweight with the other limbs for long term. Therefore, it is important to diagnose bone disease in the initial state.

In the case of Thoroughbreds, X-ray CT and MRI are used for bone diagnosis[1)]. However, these methods are expensive and cannot measure bone quality such as elasticity. Bone quality includes elastic properties, microstructure, etc[2)]. The development of evaluation methods for bone quality has been strongly expected. The quantitative ultrasound (QUS) is attracting attention as a bone diagnostic method. QUS can easily and safely evaluate the bone quality. One QUS methods, the Axial Transmission (AT) techniques for humans are also being investigated for the diagnosis of animal bones. Wave propagation simulation using FDTD has also been conducted to support the development of QUS. However, for the development of these techniques, it is first necessary to understand the ultrasonic wave properties of bones of large animals. The properties may be different from humans. In this study, ultrasonic properties (wave velocity and attenuation) of the third metatarsal cortical bone of Thoroughbreds were evaluated experimentally.

2. Experimental Methods

2.1. Experimental Samples

The cortical bone sample was cut out from the diaphysis of right third metatarsal bone of a Thoroughbred (100 months old, weight 540 kg, male) (Fig. 1). The sample was processed into eight cubes of approximately 7 mm on each side. Thereafter, the specimens were identified by the initials of each part. For example, the anterior part is denoted by A and the anterior-lateral part by AL. The thickness and weight of each specimen were measured using a micrometer (IP65 coolant proof, Mitutoyo) and an electronic balance (AUX320, D449625377, Shimadzu). During measurements, each sample was fully degassed in water. The microstructure of the specimen surface was observed using an electron microscope (VW-9000 High Speed Microscope, KEYENCE). Bone mineral density (BMD) was measured using high-resolution peripheral quantitative computed tomography (HR-pQCT; Xtreme CT II, SCANCO Medical AG, Brüttisellen, Switzerland).

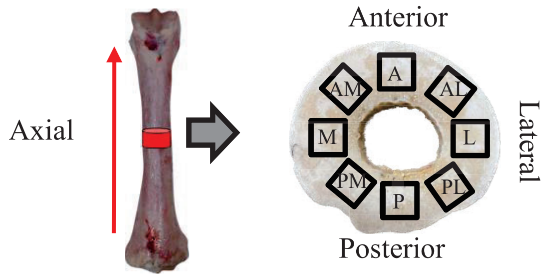

Fig.1 Cortical part of third metatarsal bone of thoroughbred

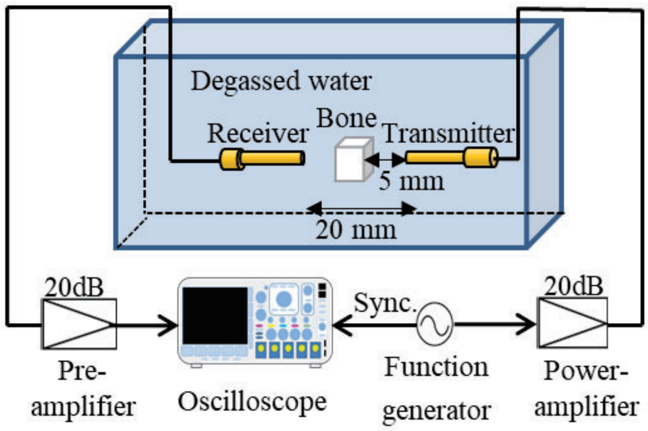

Fig.2 Experimental system for ultrasonic properties measurement

2.2. Ultrasonic wave properties in cortical bone

Figure 2 shows the experimental system. The transmitter and receiver (3 mm in diameter, self-made planar PVDF transducer) were coaxially set with distance of 20 mm in degassed water. A bone sample was placed 5 mm from the transmitter. Ultrasonic waves from 6 to 9 MHz were transmitted through the sample. The received wave was observed for each specimen. The wave which passed only in water was also observed. The wave velocity in the

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bone specimen was obtained from the arrival time difference of the wavefronts of the observed waveforms. The attenuation of each bone sample was calculated from the density, wave velocity, and peak-to-peak value of the observed waveform.

3. Result and Discussion

Density, wave velocity and attenuation at 6 MHz are shown in Figs.3, 4 and 5. The bone surface microstructures of A and P are shown in Figs. 6 (a) and (b).

The wave velocity in the axial direction was about 3800 m/s for P and about 4200 m/s for the others. This indicates a slight softening in the posterior region. This trend is consistent with that of large animals such as bovine. The wave velocities in the radial and tangential directions were about 3300-3400 m/s and almost identical.

The reason for the large attenuation of P and PL may be the influence of bone microstructure. The bone surfaces of all specimens showed haversian structure (haversian tubes with a diameter of about 10-50 μm). However, in the P and PL samples, diameters were 100 μm or more. These tubes might scatter the waves, resulting in the increase of attenuation. The BMD also showed small values in P and PL specimens, which results in the small mass density. In the radial and tangential directions, the attenuations were high. This may result from the anisotropy of the heversian tubes and voids. The similar velocities in the radial and tangential directions mean uniaxial anisotropy.

4. Conclusion

Ultrasonic wave properties in the MHz range were evaluated in the third metatarsal cortical bone of Thoroughbreds. The wave velocity and density varied due to the site but showed uniaxial anisotropy. Since human bone also has haversian structure like horses, human bone may be uniaxially anisotropic.

The relationship between mass density and attenuation suggests that voids may affect attenuation. However, of course, the material properties of bone matrix, which is mainly made from collagen and hydroxyapatite should also be investigated in the next step.

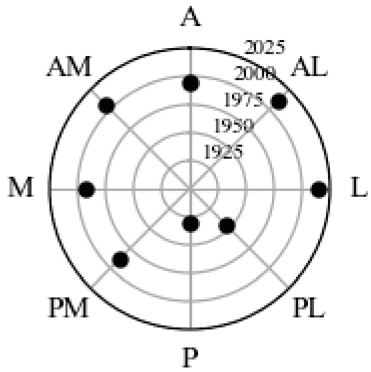


Fig.3 Density [kg/m^3]

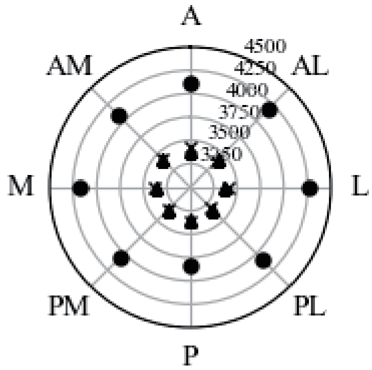


Fig.4 Wave velocity [m/s]
(Axial:●, Radial:✖,Tangential:▲)

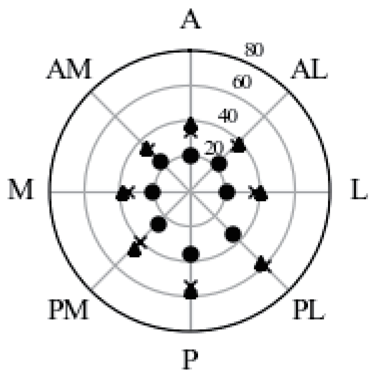
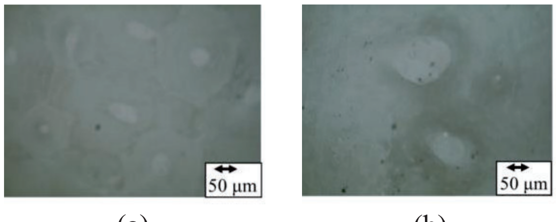


Fig.5 Attenuation [dB/cm]
(Axial:●, Radial:✖,Tangential:▲)



(a) (b)

Fig.6 Microstructure of bone surface
(a)Anterior (b) Posterior

References

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